Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

CALCULATION COVER SHEET

Supersedes Calculation No.:	Total Number of Attachments:
Analyzed System: E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure	
Purpose of Revision: Initial Issue	

PREPARER

Print Name	Signature	Date
P. S. Strons, NE-EO		

REVIEWER

Print Name	Signature	Date

VENDOR APPROVER (if vendor-supplied calculation)

Print Name	Signature	Date
n.a.		

FINAL APPROVER

Print Name	Signature	Date

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

TABLE OF CONTENTS

COVER SHEET 1
TABLE OF CONTENTS 2
LIST OF EFFECTIVE PAGES 3
1 Objectives 4
2 Limitations 4
3 Acceptance Criteria 4
4 Methodology 5
5 Assumptions 5
6. Calculation 8
7 Conclusions 15
8 References 15
9 Computer Software Specifications 15

APPENDICES
Appendix A-K – Calculation back-up and Commercial reference 16

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

LIST OF EFFECTIVE PAGES

Pages	Revision
1 to 27	0

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

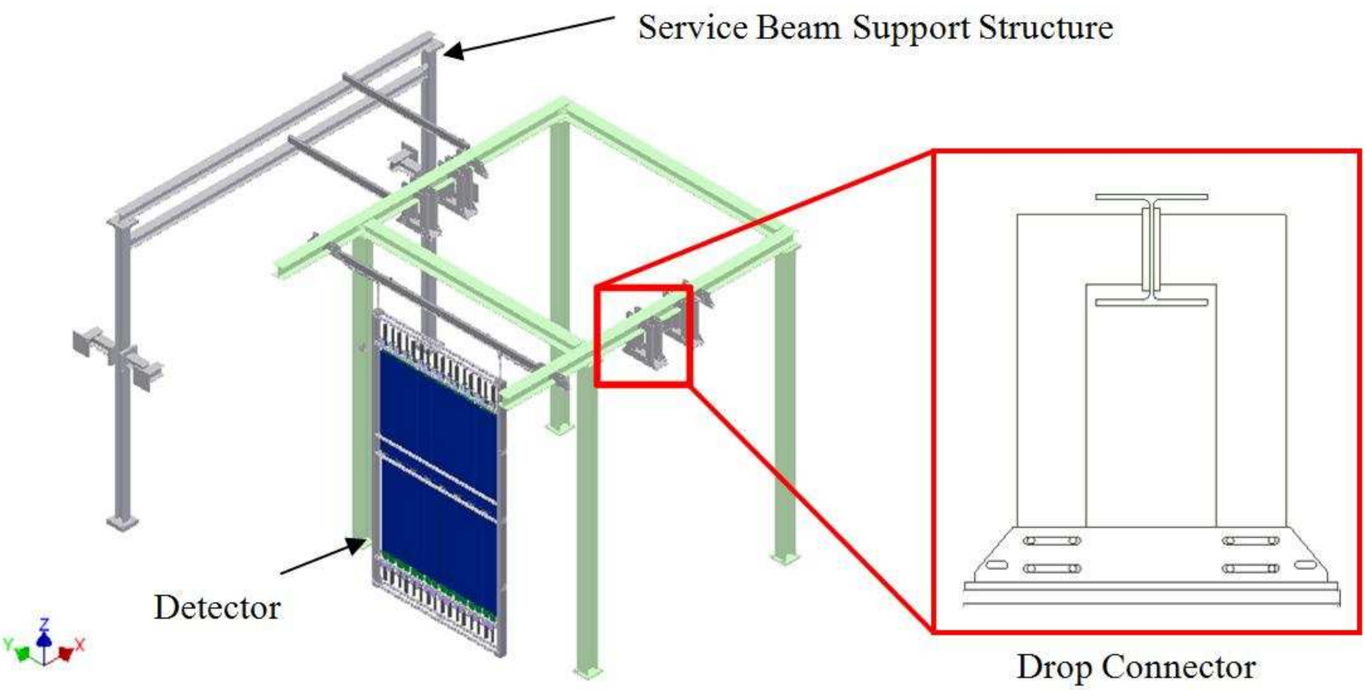

Figure 1 Drop Connectors and Service Beam Support Structure

1Objectives

The purpose of this note is to document the calculations confirming that the design of E906 Stations 3 & 4 Drop Connectors and the Service Beam Support Structure (see Figure 11) meet requirements of Allowable Strength Design (ASD) as defined by The AISC Steel Construction Manual, 13th Edition.

2Limitations

This analysis is limited to the Service Beam Support Structure and the Drop Connectors, the components that connect the detectors to the E906 Station 3 & 4 Support Frame. The analysis is contingent upon the use meeting the assumptions specified in section 5.

3Acceptance Criteria

The acceptance criteria are to meet the requirements of the AISC Steel Construction Manual 13th Edition, using ASD. The requirements are defined in Part 16, Specifications and Codes.

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

4Methodology

The methodology of calculation was based on static elastic analysis following the AISC Steel Construction Manual code to determine the allowable loading in the structure.

5Assumptions

The following assumptions are made with regard to the construction of the drop connectors and the service beam support structure:

- The material used for construction of the connectors and the service beam structure is A36 steel
- Bolts used in connections are A325 based on bolt head markings in photos
- Filler metal used in welds is type E60XX
- All bolted connections are bearing-type connections only
- The detector support beams rest on the bottom of the Drop Connectors and transmit their load by contact and the bolts that secure it to the connector do not carry any load
- The shorter Drop Connectors would have lower loading due to shorter moment arms and are therefore adequate if the longer Drop Connectors are adequate
- Load data from previous FEA performed on the E906 detector support frame is assumed to be correct
- The beams of the service beam support structure are simply connected to the columns (i.e. no moments are transferred to the columns)
- Only one detector array will be in the service position at a time

5.1 **Drop Connector design**

The design of the Drop Connector is described by the 3D models h4y_5x2_double_plate_drop.iam and h4y_5x2_plate_drop_bottom.iam.

5.2 **Drop Connector applied loads**

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

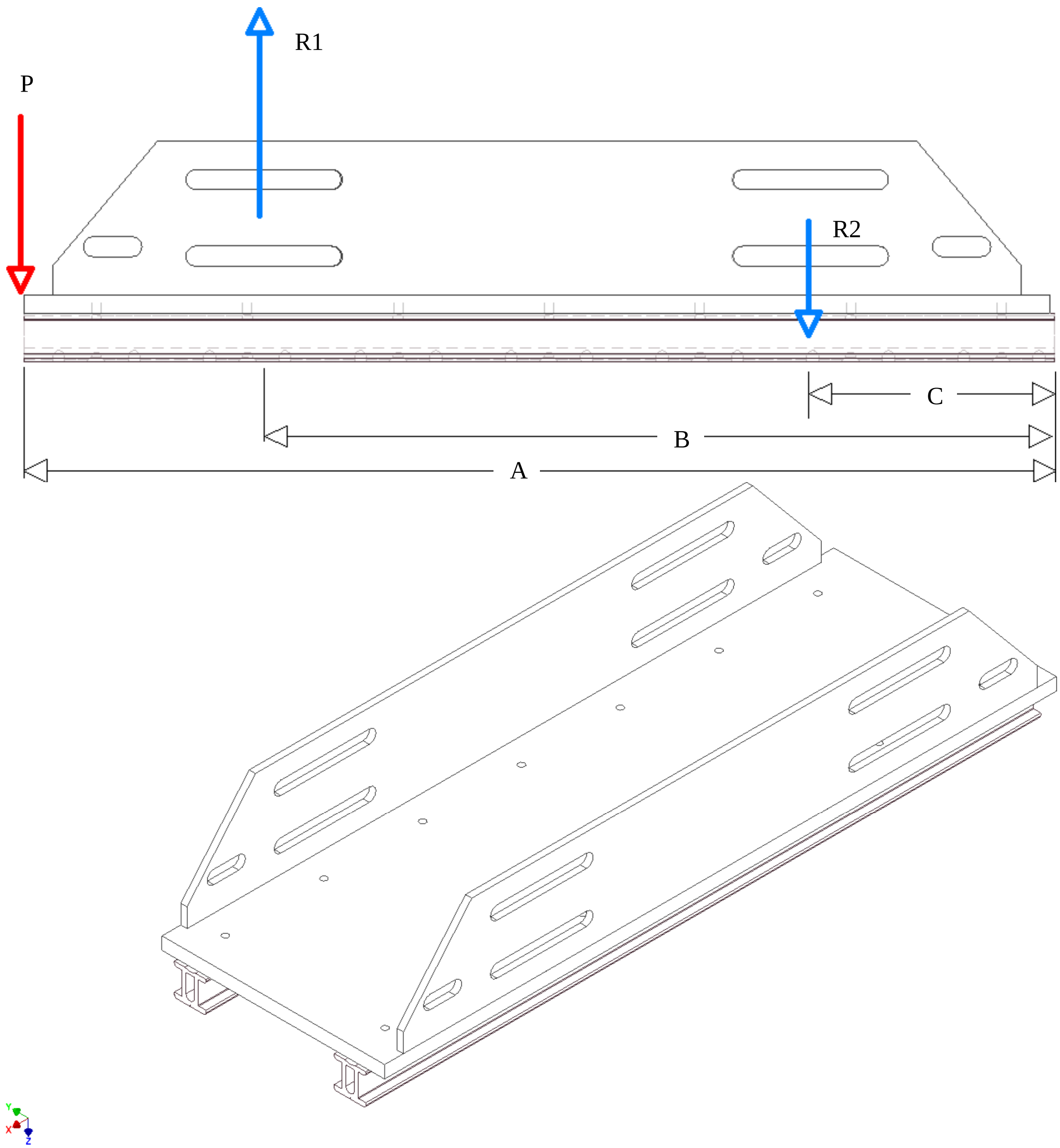

Figure 2 Free body diagram of the bottom portion of the Drop Connector is shown above. The distances A, B, and C are used to sum the moments about a common point. Below is an isometric view of the component.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

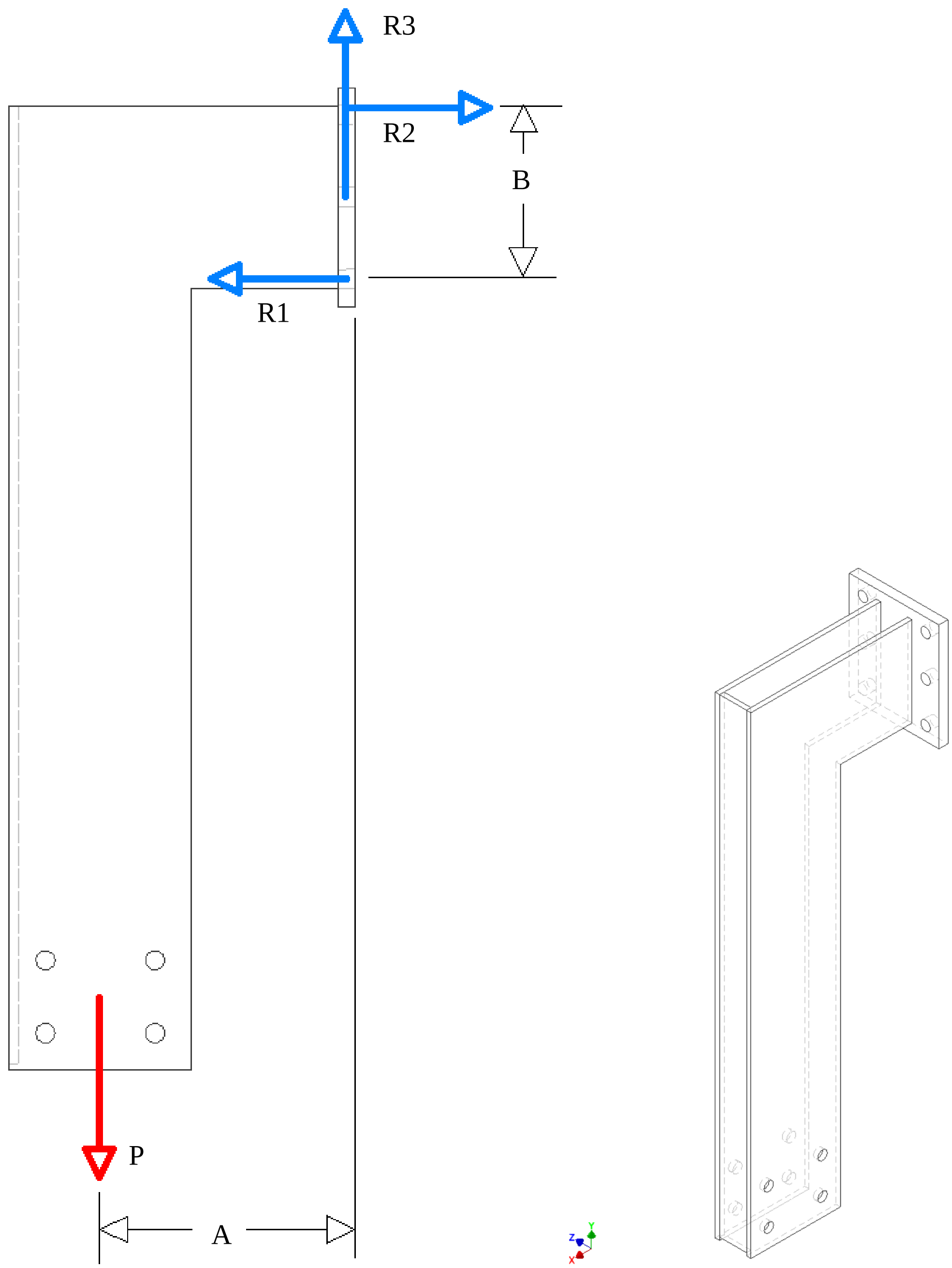

Figure 3 On the left is a free body diagram of the top portion of the Drop Connector. The distances A and B are used to sum the moments about a common point. An isometric view is shown on the right.

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

5.3 **Service Beam Support Structure design**

The design of the Service Beam Support Structure is described by the 3D model service_beam_frame.iam.

5.4 **Service Beam Support Structure applied loads**

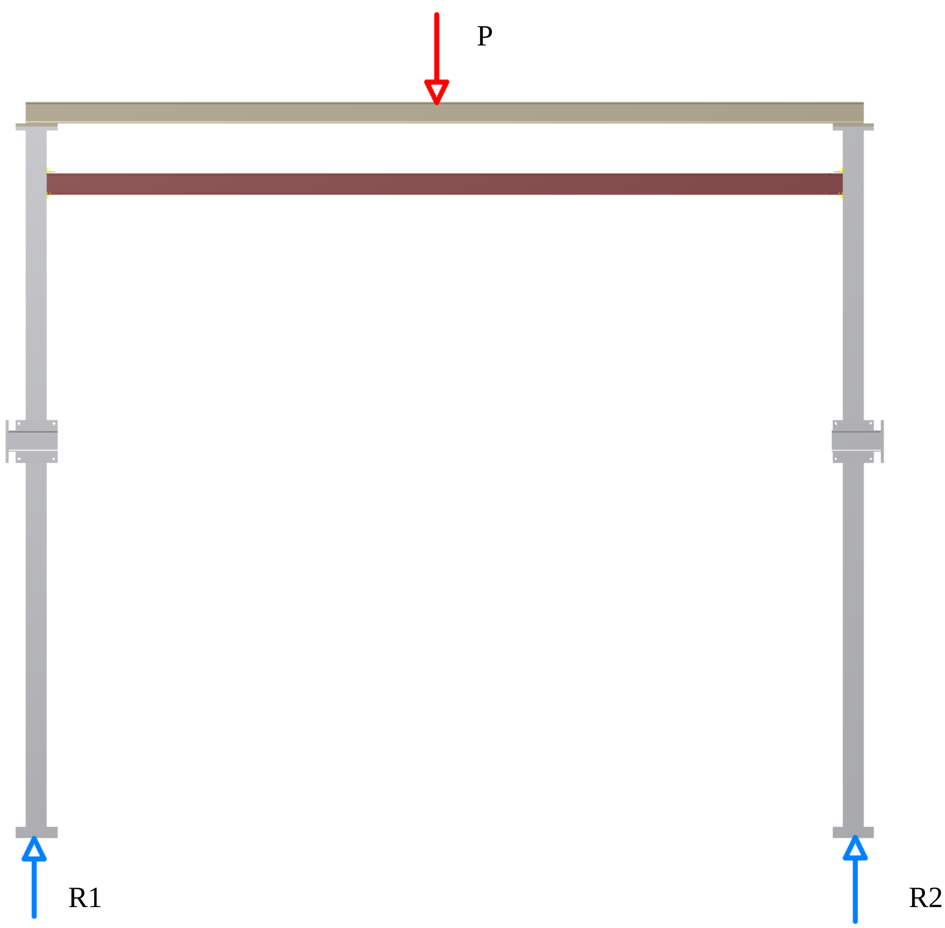

Figure 4 Free body diagram of Service Beam Structure.

6. Calculation

6.1 **General description of loads and components analyzed.**

Force data for this calculation was taken from the spreadsheet Layout_29_july_2010_plus_modified.xls, which was used by Rick Fischer in his FEA of the detector frame. The free body diagram for the Drop Connector worst loading case is shown in Figure 2 and 3. This connector supports the two Station 4a prop tubes, each applying a load of 870 lbs to the connector. For simplicity, only one side of the connector, both top and bottom portions was analyzed, assuming that each half of the connector carries the load of one detector, which is 870 lbs.

Figure 2 shows that by summing the forces in the vertical direction and summing the moments from those forces yields reaction forces of R1 = 1253 lbs and R2 = 383 lbs in the directions shown by the blue arrows. See the appendix for the details of the calculation.

R1 from Figure 2 becomes the applied load P in Figure 3. By examination of the photo below of the as-built geometry of the top portion of the connector, it can be seen that the top and bottom bolt holes are slotted and cannot carry any vertical load. This makes R1 and R2 equal in magnitude, as well as P and R3 being equal in magnitude. Since P is already known, R3 is simply 1253 lbs in the direction shown in Figure 3. By summing moments, we find that R1 and R2 have the value of 1949 lbs. in the directions shown. Details of this calculation are in the appendix.

Figure 5 Photo of the as-built geometry at the top end of the connector.

Figure 4 shows the beams and columns of the Service Beam Support Structure. There are two beams because the various detectors are supported at either height depending on the location of the center height of the individual detector. Only one detector applies a load to only one beam at any time. The worst case load from one detector of 870 lbs is applied as a point load at the center of the beam. Including the weight of the 20 ft beam of 21 lbs/ft gives a worst case moment on the beam of 5400 ft-lbs. For a worst case scenario loading of one of the columns, the total detector load plus half the weight of the beams, a total load of 1290 lbs, is assumed to be supported by one column.

6.2 Bolted connection on bottom portion of Drop Connector

The reaction force R1 shown in Figure 2 is transmitted to the top portion of the connector through four bolts, two in each slot. Section J3.6 gives the allowable shear based on the shear strength for A325 bolts. The ASD safety factor is 2.00. The allowable shear force on the four bolts is 18,850 lbs., but the load is only 1253 lbs. Therefore, the bolts are strong enough for this connection

The bearing strength of the slotted holes for the four bolts is given by Section J3.10. It is based on the minimum tensile strength of the material (58 ksi for A36 steel), the clear distance from the edge of the hole to the edge of the material, and the thickness of the material. The ASD safety factor is 2.00. The allowable force on the slotted holes is 5329 lbs, which is greater than the load of 1253 lbs. So, the slotted holes can handle the applied load.

6.3 Welded connection between the bottom plate and the vertical plates

There are 5 groove welds, each 2" long, between the bottom plate and the vertical plates of the bottom portion of the Drop Connector, and the welds are on both sides of each of the vertical plates. The throat of the welds is 5/16". See Figure 6 below.

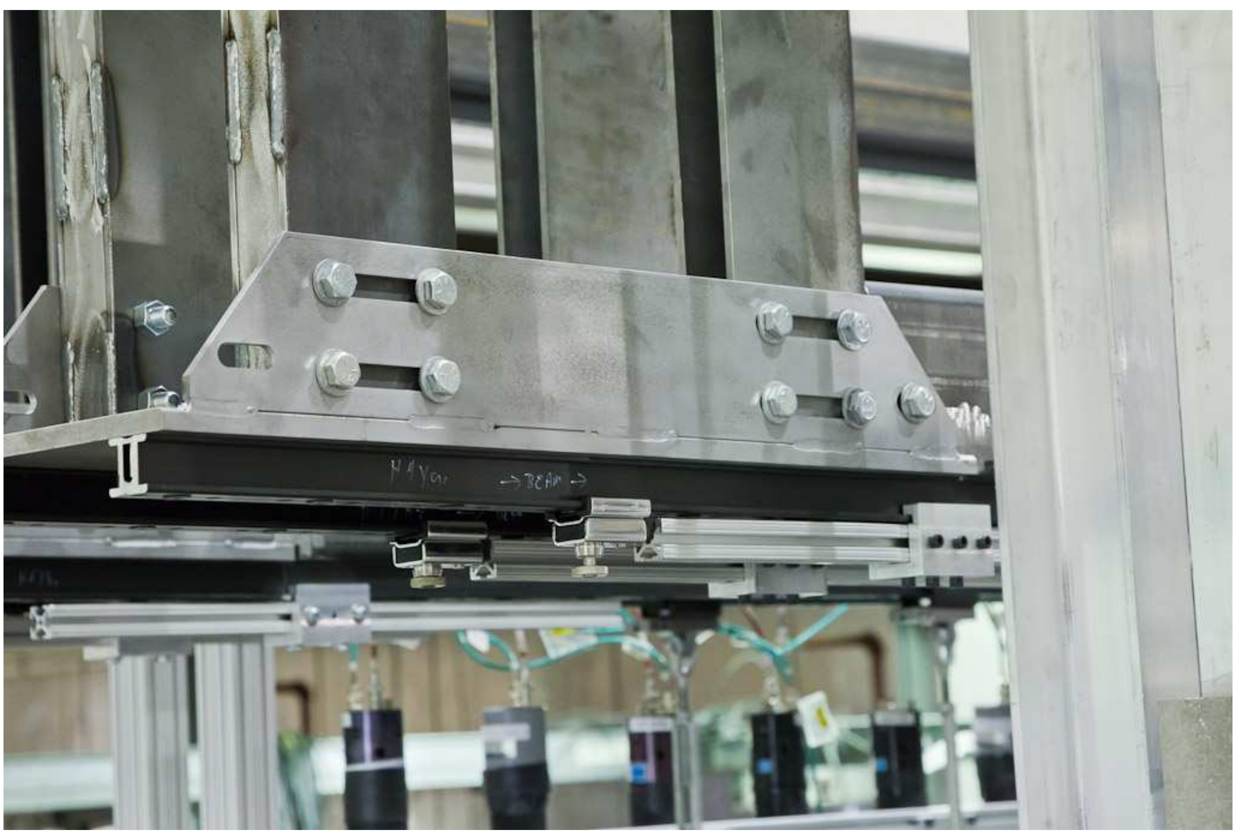

Figure 6 Photo of the groove welds on the bottom portion of the Drop Connector

Assuming only partial joint penetration welds, the strength of the weld joint in this case is found in Section J2.4, Table J2.5. The area of the base metal that is welded is 2.5 in^2. The strength of the base metal is determined by Section J4.1. In this case, tensile yielding is the limiting factor. The allowable tensile yielding strength is 54,000 lbs. The nominal strength of the filler metal is 36 ksi. The allowable strength of the weld metal is 47,870 lbs. The load of 1253 lbs. is well under these limits.

6.4 Strength of the vertical plate in the bottom portion of the connector

The strength of connecting elements in tension is determined by the lesser of the tensile yielding strength or tensile rupture (Section J4.1). In this case, tensile rupture is the smaller limit with an allowable strength of 84,000 lbs.

6.5 Strength of bolts on the top portion of the Drop Connector

Two bolts carry the vertical or shear load for the top portion of the Drop Connector. Section J3.6 defines the allowable shear on bolts. The bolts have a nominal diameter of ½" and support a load of 1253 lbs. The allowable shear strength for this case is 9,425 lbs.

The two bolts at the top of the bolt pattern for the top portion of the Drop Connector are in tension with a total load of 1949 lbs. The allowable tensile strength for bolts is also defined by Section J3.6. It is based on the nominal tensile strength of the bolts defined in table J3.2. The allowable tensile load is calculated as 17,670 lbs.

6.6 Shear strength of welds at top portion of Drop Connector

The weld that connects the bolt plate to the rest of the top portion of the Drop Connector is a ¼" fillet weld (0.177" throat) that is 5" in length on each side for a total weld area of 1.768 in^2. The nominal weld strength for type 60XX filler metal is 36 ksi. The allowable shear strength for this weld is 31,820 lbs.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

Figure 7 Photo showing the weld detail at the top of the Drop Connector

6.7 Strength of Service Beam Support Structure columns

The columns are W6x15 wide-flange I beams. The height of the column from the base to the tallest connection is 16’-4”. The connections with the beams have been redesigned to not transfer any moment to the columns. See Figure 8 below.

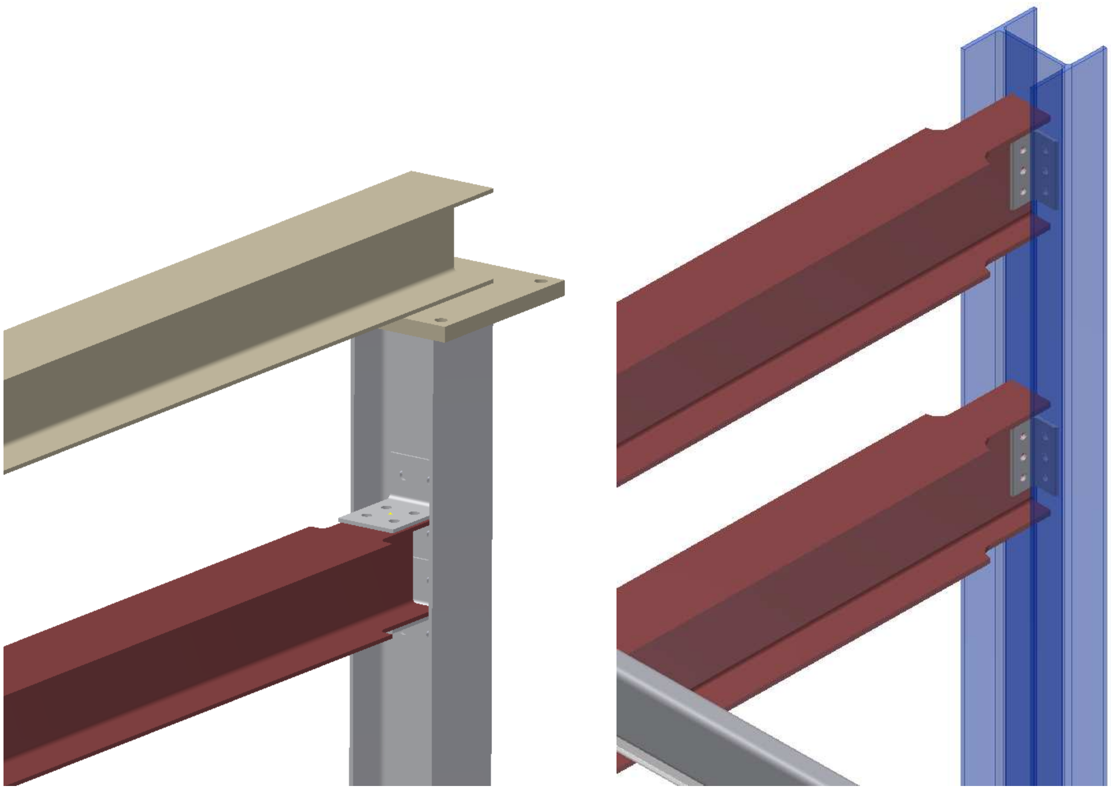

Figure 8 Original design of beam connections is shown on the left. The proposed design, which is on the right, is intended to eliminate the transfer of moments from the beams to the columns.

Section E3 determines nominal compressive strength based on the limit state of flexural buckling. The flexural buckling stress in this case is 13.7 ksi. The cross-sectional area of the W6x15 column is 4.43 in^2. With the ASD safety factor of 1.67, the allowable strength of the column is 36,440 lbs. The load on the column is only 1290 lbs.

6.8 Strength of Service Beam Support Structure beams

The original beam design called for a W6x15 size section. Using Section F3 of the Steel Construction Manual showed that this was insufficient. Based on the applied load and the resulting moment, a W8x21 beam was selected as a replacement. The W8x21 section has a compact flange and compact web, so the limit states are yielding and lateral-torsional buckling, which falls under Section F2. For yielding, the nominal moment is 61,200 ft-lbs, with the allowable being 36,650 ft-lbs. For lateral-torsional buckling the allowable moment is 23,730 ft-lbs. The applied moment from the 870 lb detector and the weight of the beam is 5400 ft-lbs.

6.9 Seismic Loading

Horizontal loading from seismic accelerations was determined using ASCE 7-05 Minimum Design Loads for Buildings and Other Structures. In particular, chapters 11, 13, and 15 were referenced. A force derived from the total mass of the service beam support structure and the heaviest weight for a detector was used as the horizontal force. The value for the horizontal force was calculated as 88.2 lbs. In the previous calculations of allowable strengths, the lowest value was for the bearing strength of the bolt holes on the drop connector. This value was 5329 lbs. If the seismic design force is combined with the calculated load on the bolt holes as vectors, the load becomes 1256 lbs, which is still below the allowable force. Even if the seismic design force is added to the calculated load as scalar values, 1341 lbs, the value is still below the allowable force.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

7Conclusions

7.1 The drop connector design analyzed within this document under the assumptions presented in section 5 meets the requirements as set out in the acceptance criteria in section 3.

7.2 The service beam support structure design analyzed within this document under the assumptions presented in section 5 meets the requirements as set out in the acceptance criteria in section 3.

7.3 The connections in the service beam support structure are deemed to be adequate by inspection by comparing loading and dimensions to the drop connector.

7.4 Seismic loading does not cause any of the components to exceed allowable strengths.

8References

1. AISC Steel Construction Manual 13th Edition

2. ASCE 7-05 Minimum Design Loads for Buildings and other Structures

9Computer Software Specifications

Mathcad 14.0 M020 (14.0.2.5) Parametric Technology Corporation

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

APPENDIX 1
GENERAL CHECKING CRITERIA SHEET

CALCULATION CHECKLIST	**Yes**	**No**	**N/A**	**Comments**
1. Are analytical methods appropriate?	☐	☐	☐	
2. Are assumptions appropriate?	☐	☐	☐	
3. Is the calculation complete?	☐	☐	☐	
4. Is the calculation mathematically accurate?	☐	☐	☐	
5. Do calculation parameters comply with design criteria/dimensions?	☐	☐	☐	
6. Were input data appropriate?	☐	☐	☐	
7. Does the calculation reference or list applicable assumptions and major equation sources?	☐	☐	☐	
COMPUTER CODE CHECKLIST	**Yes**	**No**	**N/A**	**Comments**
1. Was an applicable and valid computer program used?	☐	☐	☐	
2. Are the input assumptions appropriate?	☐	☐	☐	
3. Was the input entered correctly?	☐	☐	☐	
4. Do the input results seem reasonable?	☐	☐	☐	

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

APPENDIX 1
GENERAL CHECKING CRITERIA SHEET

ADDITIONAL COMMENTS		
Number	**Comment**	**Resolution**
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

Appendices A-L Calculation back-up

See following pages.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

A. Forces on drop connector bottom portion:

$P := -870 \cdot lbf$ Applied load

$R1$ & $R2$ Reaction forces at bolted connections

$P + R1 + R2 = 0$ Sum of forces in vertical direction

$R2 = -P - R1$

$A := 26.784 \cdot in$ $B := 20.517 \cdot in$ $C := 6.267 \cdot in$ Distances of forces from right edge

$P \cdot A + R1 \cdot B + R2 \cdot C = 0$ Sum of moments

$P \cdot A + R1 \cdot B + (-P - R1) \cdot C = 0$

$$R1 := \frac{-P \cdot (A - C)}{(B - C)} = 1.253 \times 10^3 \cdot lbf$$

$R2 := -P - R1 = -383 \cdot lbf$

B. Allowable shear on bolts (Section J3.6) for the bottom portion of the connector:

$F_{nv} := 48 \cdot ksi$ nominal shear stress from Table J3.2

$n := 4$ number of bolts $d := 0.5 \cdot in$ nominal bolt diameter

$A_b := n \cdot \left(\frac{\pi}{4} \cdot d^2 \right) = 0.785 \cdot in^2$ area of bolts

$R_n := F_{nv} \cdot A_b = 37.699 \times 10^3 \cdot lbf$ nominal shear strength of bolted connection (J3-1)

$\Omega := 2.00$ ASD safety factor $R_a := \frac{R_n}{\Omega} = 18.85 \times 10^3 \, lbf$ allowable shear strength

$R1 < R_a$ therefore, bolts have adequate shear strength

C. Bearing strength at bolt holes (Section J3.10):

$F_u := 58 \cdot ksi$ minimum tensile strength of the material

$L_c := 0.735 \cdot in$ clear distance from edge of hole to edge of material

$t := 0.25 \cdot in$ thickness of material

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

$R_n := 1.0 \cdot L_c \cdot t \cdot F_u = 10.657 \times 10^3\ lbf$ nominal bearing strength, Equation (J3-6c)

$\Omega := 2.00$ ASD safety factor

$R_a := \frac{R_n}{\Omega} = 5.329 \times 10^3\ lbf$ allowable bearing strength

$R1 < R_a$ therefore, bolt holes have adequate bearing strength

D. Strength of connecting elements in tension (Section J4.1):

Calculated for the vertical plate of the bottom portion of the drop connector.

Allowable strength is the lesser of tensile yielding or tensile rupture.

$A_g := 19.83 \cdot in \cdot 0.25 \cdot in = 4.957\ in^2$ Gross area of element section

$F_y := 36 \cdot ksi$ Yield stress of A36 steel

$R_n := F_y \cdot A_g = 178.470 \times 10^3\ lbf$ Nominal tensile yielding strength

$\Omega := 1.67$ ASD safety factor

$R_a := \frac{R_n}{\Omega} = 106.868 \times 10^3\ lbf$ Allowable tensile yield strength

$A_e := 19.83 \cdot in \cdot .25 \cdot in - 2 \cdot (4.096 \cdot in \cdot .25 \cdot in) = 2.909\ in^2$ Effective area of element section

$F_u := 58 \cdot ksi$ Ultimate tensile strength of A36

$R_n := F_u \cdot A_e = 168.751 \times 10^3\ lbf$ Nominal tensile rupture strength

$\Omega := 2.00$ ASD safety factor

$R_a := \frac{R_n}{\Omega} = 84.375 \times 10^3\ lbf$ Allowable tensile rupture strength

R1 is less than both the allowable tensile yield and tensile rupture strengths; therefore strength of element is adequate.

E. Strength of weld joint in bottom portion (Section J2.4, Table J2.5)

(Weld is 1/4" groove weld in 5 places, each 2" long, assumed to be partial-penetration)

Base metal strength

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

$A_g := 10 \cdot in \cdot 0.25 \cdot in = 2.5\,in^2$ Gross area of base metal

$F_y := 36 \cdot ksi$ Yield stress of A36 steel

$R_n := F_y \cdot A_g = 90.000 \times 10^3\,lbf$ Nominal tensile yielding strength

$\Omega := 1.67$ ASD safety factor

$R_a := \frac{R_n}{\Omega} = 53.892 \times 10^3\,lbf$ Allowable tensile yield strength

$R1 < R_a$ therefore, base metal strength is adequate

Weld strength

$A_w := 10 \cdot in \cdot .25 \cdot in = 2.5\,in^2$

$F_{EXX} := 60 \cdot ksi$ Ultimate tensile strength of filler metal

$F_w := 0.60 \cdot F_{EXX} = 3.6 \times 10^4\,psi$ Nominal strength of filler metal

$R_n := F_w \cdot A_w = 90.000 \times 10^3\,lbf$

$\Omega := 1.88$

$R_a := \frac{R_n}{\Omega} = 47.872 \times 10^3\,lbf$

$R1 < R_a$ therefore, weld strength is adequate

F. Forces on drop connector top portion:

$P := -1253 \cdot lbf$ Applied load

$R1$ & $R2$ Horizontal reaction forces at bolted connection

$R3$ Vertical reaction force at bolted connection

$P + R3 = 0$ Sum of forces in vertical direction

$R3 := -P = 1.253 \times 10^3\,lbf$

$R1 + R2 = 0$ Sum of forces in horizontal direction

$R1 = -R2$

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

$A := 7 \cdot in$ $\quad B := 4.5 \cdot in$ Distances from common point to sum moments

$P \cdot A + R2 \cdot B = 0$ Sum of moments

$$R2 := \frac{-P \cdot A}{B} = 1.949 \times 10^3 \cdot lbf$$

$$R1 := -R2 = -1.949 \times 10^3 \, lbf$$

G. Allowable shear on bolts (Section J3.6) for the top portion of the connector:

$F_{nv} := 48 \cdot ksi$ nominal shear stress from Table J3.2

$n := 2$ number of bolts $\quad d := 0.5 \cdot in$ nominal bolt diameter

$A_b := n \cdot \left(\frac{\pi}{4} \cdot d^2\right) = 0.393 \cdot in^2$ area of bolts

$R_n := F_{nv} \cdot A_b = 18.85 \times 10^3 \cdot lbf$ nominal shear strength of bolted connection (J3-1)

$\Omega := 2.00$ ASD safety factor $\quad R_a := \frac{R_n}{\Omega} = 9.425 \times 10^3 \, lbf$ allowable shear strength

$R3 < R_a$ therefore, the two bolts in shear are adequately strong

H. Allowable tension on bolts (Section J3.6) for the top portion of the connector:

$F_{nt} := 90 \cdot ksi$ nominal tensile stress from Table J3.2

$n := 2$ number of bolts $\quad d := 0.5 \cdot in$ nominal bolt diameter

$A_b := n \cdot \left(\frac{\pi}{4} \cdot d^2\right) = 0.393 \cdot in^2$ area of bolts

$R_n := F_{nt} \cdot A_b = 35.343 \times 10^3 \cdot lbf$ nominal shear strength of bolted connection (J3-1)

$\Omega := 2.00$ ASD safety factor $\quad R_a := \frac{R_n}{\Omega} = 17.671 \times 10^3 \, lbf$ allowable tensile strength

$R2 < R_a$ therefore, the two bolts that are in tension are adequately strong

I. Weld shear strength in top portion of connector:

(From photo and measurements, appears to be 1/4" fillet, 5" in length, both sides)

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

$throat := \frac{0.25 \cdot in}{\sqrt{2}} = 0.177\,in$ throat of 1/4" fillet weld

$A_w := (throat \cdot 5 \cdot in) \cdot 2 = 1.768\,in^2$ area of weld

$F_{EXX} := 60 \cdot ksi$ Ultimate tensile strength of filler metal

$F_w := 0.60 \cdot F_{EXX} = 36.000 \times 10^3\,psi$ Nominal tensile strength of filler metal

$R_n := F_w \cdot A_w = 63.640 \times 10^3\,lbf$ Nominal strength of weld

$\Omega := 2.00$ ASD Safety Factor

$R_a := \frac{R_n}{\Omega} = 31.820 \times 10^3\,lbf$ Allowable shear strength of fillet weld

$R3 < R_a$ therefore, fillet weld has adequate shear strength

J. Compressive strength for flexural buckling of members without slender elements (Section E3)

This calculation evaluates the strength of the W6x15 columns in the service beam support structure.

$b_f := 5.99 \cdot in$ $t_f := 0.260 \cdot in$ flange dimensions

$\lambda := \frac{b_f}{2 \cdot t_f} = 11.519$ width - thickness ratio of member

$E := 29000 \cdot ksi$ $F_y := 36 \cdot ksi$ material properties of A36 steel

$\lambda_p := 0.38 \cdot \sqrt{\frac{E}{F_y}} = 10.785$ limit for compact sections (Table B4.1)

$\lambda_r := 1.0 \cdot \sqrt{\frac{E}{F_y}} = 28.382$ limit for noncompact sections (Table B4.1)

$\lambda_p < \lambda < \lambda_r$ therefore section is considered noncompact

$k := 1$ effective length factor determined in accordance with Section C2

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

$L := 16 \cdot ft + 4 \cdot in$ laterally unbraced length of member

$r := 1.45 \cdot in$ governing radius of gyration, taken from Table 1-1

$\frac{k \cdot L}{r} = 135.172$ column slenderness ratio

$4.71 \cdot \sqrt{\frac{E}{F_y}} = 133.681$ when slenderness ratio exceeds this value, Equation E3-3 applies

$F_e := \frac{\pi^2 \cdot E}{\left(\frac{k \cdot L}{r}\right)^2} = 15.665 \cdot ksi$ first determine elastic critical buckling stress from Equation E3-4

$F_{cr} := 0.877 \cdot F_e = 13.738 \cdot ksi$ flexural buckling stress Equation E3-3

$A_g := 4.43 \cdot in^2$ gross cross sectional area of member from Table 1-1

$P_n := F_{cr} \cdot A_g = 60.859 \times 10^3 \, lbf$ nominal compressive strength

$\Omega_c := 1.67$ ASD Safety Factor

$\frac{P_n}{\Omega_c} = 3.644 \times 10^4 \, lbf$ allowable strength of column

$P := 870 \cdot lbf + 420 \cdot lbf = 1.29 \times 10^3 \, lbf$ applied load to column

$P < \frac{P_n}{\Omega_c}$ therefore, column has adequate strength

K. Doubly symmetric compact I-shaped members bent about their major axis (Section F2)

Suggested beam size of W6x15 was found to be inadequate to support the applied load. A W8x21 beam was chosen to replace it.

$b_f := 5.27 \cdot in$ $t_f := 0.40 \cdot in$ dimensions of W8x21 flange

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

$\lambda := \dfrac{b_f}{2 \cdot t_f} = 6.587$ width - thickness ratio

$\lambda < \lambda_p$ therefore section is compact according to Table B4.1

The nominal flexural strength shall be the lower value according to the limit states of yielding and lateral-torsional buckling.

$L := 20 \cdot ft$ length of beam

$P := 870 \cdot lbf$ applied point load on beam

$M := \dfrac{P \cdot L}{4} + 1050 \cdot ft \cdot lbf = 5.4 \times 10^3 \cdot ft \cdot lbf$ applied moment on beam from point load and weight of beam

Section F2.1 Yielding:

$Z_x := 20.4 \cdot in^3$ plastic section modulus about x-axis, from Table 1-1

$F_y = 36 \cdot ksi$ minimum yield stress of A36 steel

$M_p := F_y \cdot Z_x = 6.12 \times 10^4 \cdot ft \cdot lbf$ plastic moment

$M_n := M_p$ nominal flexural strength

$\Omega_b := 1.67$ ASD Safety Factor

$M_a := \dfrac{M_n}{\Omega_b} = 3.665 \times 10^4 \cdot ft \cdot lbf$

$M < M_a$ therefore beam does not yield

Section F2.2 Lateral-torsional buckling (LTB):

$L_b := L = 20 \cdot ft$ unbraced length of beam

$r := 1.26 \cdot in$ radius of gyration in x-axis, from Table 1-1

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: **NE-EO-2011-002**	Revision Number: 0

$$L_p := 1.76 \cdot r \cdot \sqrt{\frac{E}{F_y}} = 5.245 \cdot ft$$ lower limit for LTB

The next row of parameters are needed to determine Lr, and are taken from Table 1-1

$S_x := 18.2 \cdot in^3$ $r_{ts} := 1.46 \cdot in$ $J := 0.282 \cdot in^4$ $h_o := 7.88 \cdot in$

$c := 1$ from (F2-8a)

$$L_r := 1.95 \cdot r_{ts} \cdot \frac{E}{0.7 \cdot F_y} \cdot \sqrt{\frac{J \cdot c}{S_x \cdot h_o}} \cdot \sqrt{1 + \sqrt{1 + 6.76 \cdot \left(\frac{0.7 \cdot F_y}{E} \cdot \frac{S_x \cdot h_o}{J \cdot c}\right)}} = 20.959 \cdot ft$$

$L_p < L_b < L_r$ therefore nominal flexural strength for LTB determined by Equation F2-2

$C_b := 1$ permitted to be conservatively taken as 1.0 for all cases

$$M_n := C_b \cdot \left[M_p - \left(M_p - 0.7 \cdot F_y \cdot S_x\right) \cdot \left(\frac{L - L_p}{L_r - L_p}\right)\right] = 3.962 \times 10^4 \cdot ft \cdot lbf$$

$$M_a := \frac{M_n}{\Omega_b} = 2.373 \times 10^4 \cdot ft \cdot lbf$$

$M < M_a$ therefore beam is strong enough to prevent LTB

Title:	Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.:	**NE-EO-2011-002**	Revision Number: 0

L. Seismic design force from ASCE 7-05

$S_s := 0.20 \cdot g$ Acceleration parameter from Figure 22-1

$F_a := 1.0$ Site coefficient from Table 11.4-1

$S_{MS} := F_a \cdot S_s = 0.2 \cdot g$ Adjusted acceleration parameter from eqn. 11.4-1

$S_{DS} := \frac{2}{3} \cdot S_{MS} = 0.133 \cdot g$ Design acceleration parameter from eqn. 11.4-3

Weights of service beam structure components and detector:

$w_{beam} := 21 \cdot \frac{lbm}{ft} \cdot 20 \cdot ft = 420\, lb$

$w_{column} := 15 \cdot \frac{lbm}{ft} \cdot 16.5 \cdot ft = 247.5\, lb$

$w_{det} := 870 \cdot lbm$

$W_p := 2 \cdot w_{beam} + 2 \cdot w_{column} + w_{det} = 2.205 \times 10^3\, lb$ Combined weight

$a_p := 1.0$ component amplification factor from Table 13.5-1

$I_p := 1.0$ component importance factor from Section 13.1.3

$R_p := 1.5$ component response modification factor from Table 13.5-1

$F_p := \frac{0.4 \cdot a_p \cdot S_{DS} \cdot W_p}{\frac{R_p}{I_p}} = 78.4\, lbf$ Seismic design force from eqn. 13.3-1

$F_p := 1.6 \cdot S_{DS} \cdot I_p \cdot W_p = 470.4\, lbf$ Maximum value for design force from eqn. 13.3-2

$F_p := 0.3 \cdot S_{DS} \cdot I_p \cdot W_p = 88.2\, lbf$ Minimum value for design force from eqn. 13.3-3